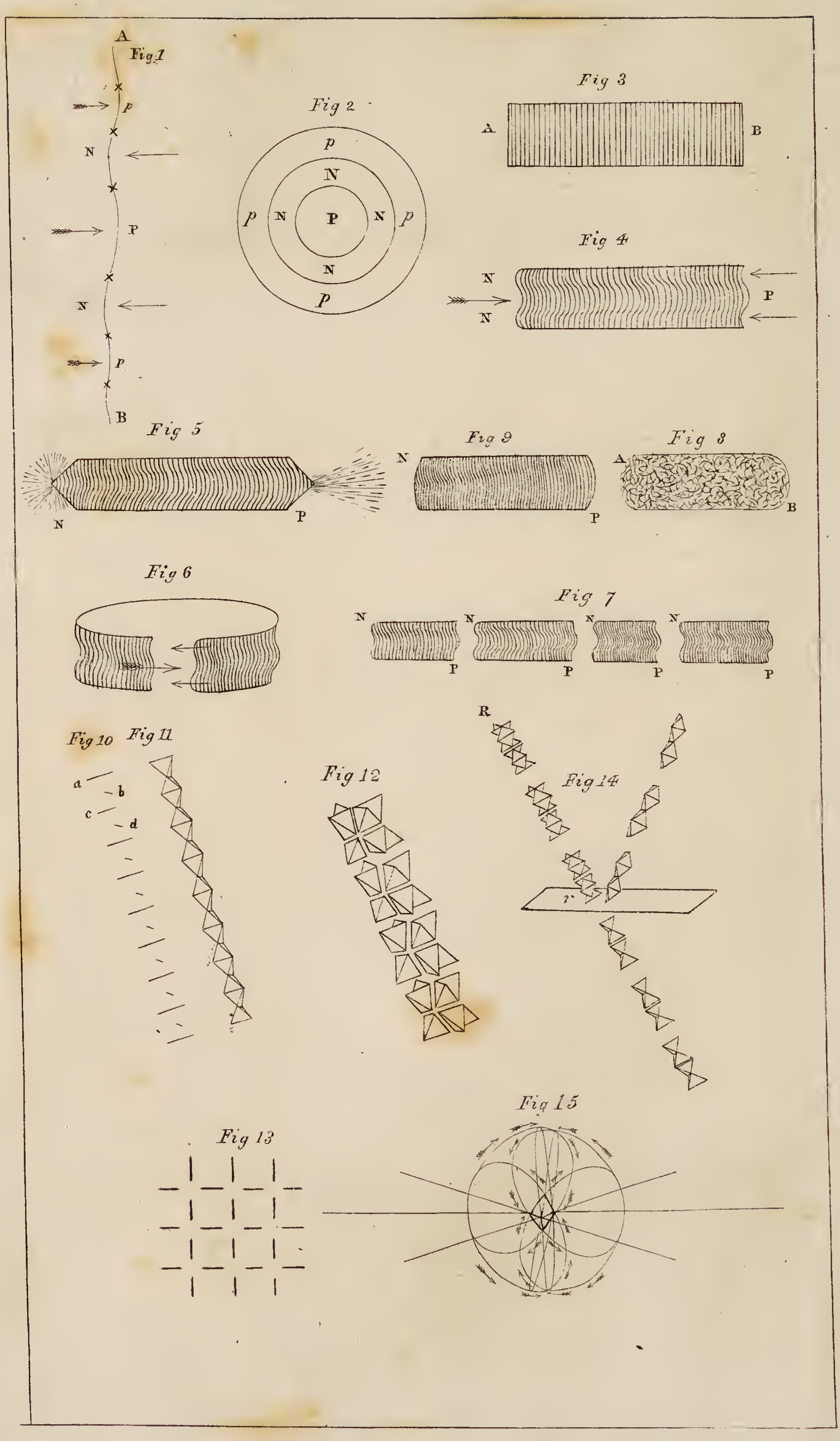
Fig 1
A
p
N
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N
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Fig 2
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Fig 3
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Fig 4
N
N
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Fig 5
N
P
Fig 9
N
P
Fig 8
A
B
Fig 6
Fig 7
N
P
N
P
N
P
N
P
Fig 10
a
b
c
d
Fig 11
Fig 12
R
Fig 14
r
Fig 13
Fig 15

AN ATTEMPT

TO

SIMPLIFY THE THEORIES

OF

ELECTRICITY AND LIGHT.

TO WHICH IS ADDED

THE RESULT OF A SPECULATION AS TO THE STRUCTURE AND ACTION OF THE MOLECULES OF BODIES.

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PREFACE.

THE following Tract has grown under the pen, so as to consist of three parts instead of one, as originally intended. The first part, and that which suggested the other two, relates to the nature of ELECTRICAL PHENOMENA, and therein the author attempts to shew that these phenomena may be explained without demanding the aid of any other hypothesis than that of an undulatory or forced-vibratory action in electric media, such as the admitted structure of these media would lead us to expect to be developed, in those circumstances in which electrical phenomena are exhibited.

The second part relates to the theory of LIGHT, and here the author endeavours to shew that the transverse vibrations assumed in the theory of Fresnel, and found to be so serviceable for explaining the phenomena of polarisation, are in point of fact indications of a certain definite form possessed by the molecules of the ether; and that, when this form is assigned to them, the theory of Huygens again becomes adequate to explain all the phenomena which the modern theory explains.

The third part relates to the structure and action of the MOLECULES of bodies; and here, by the aid of Figure 15th of the accompanying plate, the author endeavours to demonstrate mechanically that the molecular symbol or ideal molecule there represented bears such a relation to the actual molecules of bodies, that if molecules similar and analogous to it actually existed in nature, phenomena identical with those of molecular action must necessarily be exhibited by them.

And in reference to this part, the author is very happy to think that if, by filling up and particularizing the mechanism whence he endeavours to shew that the phenomena of electricity and light take their rise, he has given a form to these theories which excludes them beyond the reach of mathematical operations, and indeed by presenting a continuity of form and movement to *the direct perception* of the mind, supersedes enquiry by the *method of interpretation* altogether, he has on the other hand advanced views of molecular action which, were they borne out by nature, would at once bring the whole science of chemistry under the dominion of the science of calculation, and which, even supposing them wholly fictitious, may still afford material for the developement of a true geometrical theory full of beautiful speculations, and possessiug a most curious and interesting relation to that of physical astronomy. For this reason he had almost permitted himself to hope that the views advanced on this subject might recommend themselves to many. But on considering that at first sight his speculations seem so very bold, and

his results frequently so very dissimilar to those generally current in the present day, he judged it safer upon the whole to proceed on the supposition of having only a very few readers who, not permitting themselves to reject his views at sight, would take the pains to enquire what they are, on what evidence they stand, and to what consequences they lead. He has therefore been very brief, and condensed his views to the utmost. And were he now in a single sentence to sum up his physical researches, in reference to their philosophical bearings, he would say that the labour of years has resolved itself almost into a single result—a result however which he judges (and in as far as his own feelings are concerned he finds) not unworthy of the time bestowed on its elaboration; being calculated, if true (or indeed if believed), to fix our ideas as to the nature of the agency of matter, and the limits to which that agency can carry its operations; and thus, on our beholding (as we must do everywhere both around us and within us) another and a higher agency, to demonstrate from the light of reason those central truths, on the belief or disbelief of which the prospects of the human race mainly depend,—viz. that there is in the universe a God distinct from the material creation, and in man a soul distinct from his body, and therefore in all probability an immortality before him.

Physical science, at the present moment, is more loose and indefinite as to its first principles than ever it was in the history of philosophy before. Thus we are everywhere told that the molecules of bodies are "animated" by "forces," and yet nowhere are we informed as to the ideas which we ought to attach to such terms; or if we are, we are instructed to attach to them ideas different from those which they naturally convey—instruction, consequently, which to the great bulk of readers is wholly nugatory. In these circumstances it is not wonderful that such tenets as Pantheism and Materialism should prevail as they do; but it is very undesirable that things should continue long as they are, and much to be wished that Science were studied so as again to become entitled to the name of Philosophy.

September 2, 1834.

ON ELECTRICITY.

It is agreed on all hands that the phenomena of electricity must arise, either from the presence of a peculiar fluid or fluids in the media displaying these phenomena, or else from a peculiar mode of action in the constituent matter of such media. The question is,—Which of these hypotheses is founded in Nature? And this, it will be admitted by every one, is an inquiry of the greatest interest, particularly at the present moment when so much of the attention of philosophers is directed to electric agency.

Among the difficulties which attach to the hypothesis of peculiar fluids, the following may be enumerated :—

1. While almost all men of science admit, that the evidence for the existence of electric fluids is very equivocal, some wholly reject them. And more particularly, Dr Faraday, in the fifth of that invaluable series of papers on electricity recently read to the Royal Society, and in a *viva voce* exposition of his views, which the author of this tract had the pleasure of hearing last year at the meeting of the British Association at Cambridge, has given out, as the result of all his experimental researches up to that date, that he finds no evidence for the existence of electric fluids, and that he merely observes in electrified bodies two equivalent modes of action simultaneously taking place in opposite directions.

2. Wherever phenomena of peculiar aspect are observed, the human mind always displays a strong tendency to infer without due inquiry the presence of peculiar agents as their cause—a tendency so strong indeed as to have led to the personification of mere negatives, such as Death, Night, Ignorance, and the like. That observers therefore should have shewn a

disposition to ascribe electrical phenomena to peculiar agents is only what was to be expected, and is scarcely any argument at all in favour of the existence of such agents.

3. There is a strong temptation to adopt the hypothesis of fluids because of its mathematical convenience—a convenience which however is no argument in favour of the actual existence of these fluids, because it is only on account of the circumscribed nature and imperfect state of the calculus, that it cannot be as well applied to other hypothesis as to that of fluids. Such a state of things therefore leads us to suspect that many (and mathematicians especially) may have adopted the hypothesis of electric fluids from other considerations than the probabilities of their actual existence.

4. In order to be justified in believing in the existence of fluids possessing properties so anomalous and so unlike those of all known fluids, as the electric fluids are required to be before they can be of any service in explaining electric phenomena, we should be able to bring forward ample evidence that they really exist. But instead of this, there is no direct evidence of their existence at all. We neither see nor can otherwise detect in electrical phenomena any thing more than light and a variety of motions—that is, (supposing light mere motion, as is now generally believed,) we see in electrical phenomena nothing more than a variety of motions.

5. If we explain electrical attractions by assuming the existence of peculiar fluids as their cause, will not the principle of assigning like causes for like effects demand of us to explain all attractions by similar hypotheses, and, among others, the attraction of gravitation; so that, if we admit an electric fluid, we must also admit a gravitation fluid; and would not the latter be judged to the full as great an encumbrance in science, as the former is judged a convenience?

6. Now if in addition to these objections to the hypothesis of peculiar fluids it can be further shewn, that the phenomena considered can be better explained without their aid than with it; and especially, if it can be shewn that they can be explained without having recourse to the invention of any peculiar hypothesis, and simply by a reference to the general principles of mechanics, then, a hypothesis so peculiar as that objected to, would (I presume) cease to present longer any claims to our

regard, at least as a *physical cause* of electrical phenomena. It might still indeed be resorted to by mathematicians as a serviceable way of connecting together electrical phenomena in the language of mathematical expression. Nay, though admitted to be untrue it might still, according to the logic of a most worthy and accomplished philosopher, be held as deserving of being entertained.* But it could no longer (I presume) possess any claims to be regarded as a *vera causa*, or a statement of the actual mechanism by which electrical phenomena are developed in nature.

Such are some of the objections which present themselves at first view, to the hypothesis of peculiar fluids. Let us now proceed to consider the case of the other hypothesis already alluded to, namely, that which regards electrical phenomena as nothing more than the resultants of a peculiar mode of action in electrical media. Now this hypothesis will immediately recommend itself, in a special manner, to our regard, if independently of any view to the explanation of electrical phenomena, there appear reason for believing that in those circumstances in which electrical phenomena are displayed, there must at all events be called into existence a peculiar mode of action in bodies constituted similarly to those in which electric phenomena are displayed. Now, it plainly appears that in the circumstances alluded to, all imperfectly elastic media (in which class all bodies capable of displaying electric phenomena are included) must be thrown into a state of forced-vibratory or undulatory action. For, in the first place, it is obvious that even in the most dense bodies there are pores or spaces between the molecules ample enough to admit of these molecules vibrating through spaces much larger at least than those through which the molecules of light are supposed to vibrate in the received theory of light; and, secondly, it is certain that, however imperfectly elastic and inert some media capable of displaying electrical phenomena may be when viewed in the mass, still their intimate parts must continue sufficiently elastic for executing a vibratory action. This is plainly shewn by the fact, that when the molecules of even the most imperfectly elastic bodies are set free from the entanglements of the mechanical or plastic state in

* Sir J. Herschel, Prelim. Discourse, sect. 290.

which they are held, so as to assume the crystalline and still more the aeriform state, they prove themselves to be as elastic as others. Now, while every small impulse or disturbance in any region of a continuous medium must give rise to a propagation of motion from that point, it will be admitted (I presume) by all who are acquainted with the theory of forced vibratory action, that the constitution of the bodies described, which, in the expressive but awkward language of the Wernerian geologists, might be said to be elastic in the small and unelastic in the great, is the very constitution most favourable for the fullest developement of forced-vibratory action. What then is the form which, so far as can be traced, forced vibratory action will take on when excited in such media, and in the circumstances in which electric phenomena are developed? In answer to this inquiry, I think the following state of things must be granted:—

THE THEORY.

Let us conceive, as is usually done in such investigations, any body capable of displaying electric phenomena, (as, for instance, the wire joining the opposite poles of a galvanic arrangement,) to consist of laminæ, by the supra-position of which the cylinder or wire is produced; and each lamina to consist of filaments or thin slips, by the juxta position of which the lamina or section is produced; and let AB, Fig. 1, represent such a filament *in situ*. Then, in order to trace the mode of action which must be instituted in it, when motion is communicated as we observe it to be when electric or galvanic action is excited, let us suppose a series of momentary and elementary pressures, (such as must take place while a sustained system of friction is kept up, or during the successive incidence of similar chemical atoms, where oxidation or solution is going on,) to be made upon P in the direction of the plumed arrow. Then, must not the following mode of action ensue? 1. The central part P immediately after each impulse, must proceed in the direction of that impulse, as far as the surrounding attachments and the reaction of the contiguous parts of the medium will admit. 2. While the central part, to which the successive impulses are applied, is proceeding in the direction of these

impulses, the lateral parts NN must, in virtue of the inertia and rigidity of the medium, be simultaneously proceeding or making an effort to proceed, in directions ever tending to be exactly contrary to those of the central part P. Certain nodal regions, such as those marked in the figure with a cross, (determined in position by a variety of circumstances, such as the magnitude of the impulses impressed upon P—the aptitude of the medium for sustaining undulatory action—the magnitude and form of the intervals between the molecules, &c.) must be developed, which must serve as fulcra whereon the forced vibrations of the vibrating parts must turn and change their direction from *course* to *recourse*, and *vice versa.*

Now, if the vibrating body AB were an elastic cord freely placed in a state of tension between two fixed nuts at A and B; in a word, were its physical condition similar to that of a musical string, it is well known that the three parts thus vibrating reciprocally, would also vibrate in unison, that is, would all be equal to each other in length, and isochronous in their vibrations. But when, as here, the imperfectly elastic cord, instead of being free to vibrate between two fixed nuts, is so constituted, that every point of it is equally obstructed in its movements by a mechanism of intimate elasticity, and equally capable of becoming a node on which the vibrations may turn, according as the existing impulses are increased or diminished—and especially when it is considered, that the tension of the medium must cease to be uniform so soon as any disturbance, such as that of the primary impulses, destroys the uniformity of relationship among the molecules constituting the medium regarded as quiescent, in these circumstances, it appears to me to be demonstrable, that the law of the cycloidal pendulum cannot hold. For, in order to this, it would be necessary, not only that the mechanism which causes the *recourses* of the molecules, should be perfectly elastic, so that the resilience might be always proportional to the displacement, but that all the forces which bear upon the molecule when in and near its position of quiescence, should bear upon it also in all its phases of vibration. Now, it is next to impossible to imagine any sort of mechanism or structure, wherein such a state of things could obtain. A violent displacement of a molecule must detach or disable some of the forces or springs by which it is surrounded when

in its position of quiescence; and the greater the displacement, the greater the number of springs which we may expect to be detached or disabled—so that, even supposing the mechanism of resilience to be perfectly elastic, still the restoring force shall not increase in the same proportion as the amplitude of the vibration, but more slowly; and, therefore, we are to expect, that the larger vibration shall move more slowly than the smaller.

This argument might be put under a variety of other suppositions, all tending to shew, that what is here supposed is by far the most probable hypothesis. And with such evidence we must at present rest satisfied, because the subject does not admit of demonstration, until the actual structure and intimate mechanism of material media is discovered. In bodies very highly elastic and possessing great tenacity and symmetry of molecular structure, it is indeed conceivable, at least where the excursions of the vibrating molecules are but small, that the same forces, and these all increasing with the amount of the displacement, may act upon the vibrating molecules in all their phases, and, consequently, that the law of the cycloidal pendulum may hold, and the vibrations be isochronous whatever their amplitudes. But, in reference to gross media generally, it seems to be far safer to hold, that the times of the vibrations of the molecules must be more nearly proportional to the amount of the disturbing forces, or the amplitudes of the excursions which they are compelled to make. Hence we are led to infer, that, in such a case as that of AB (supposing it forming a part of a dense body,) the central part P, as it is more powerfully disturbed and urged to make longer excursions than the lateral parts NN, shall also vibrate more slowly. But, while it appears that such a mode of action must result in the circumstances of constraint considered, it must as uniformly tend to be destroyed by the reaction of the system, whose effect it is well known must be always one and the same, namely, to produce synchronism or rest. In order therefore to the sustained existence of the undulatory action described, an uninterrupted succession of impulses will be required.

Such is the peculiar mode of forced-vibratory action which, so far as can be discovered, must be induced upon a filament possessing a certain degree of tenacity and elasticity, or upon

a thin slip or ribbon of matter, which viewed as a whole or aggregate of molecules is imperfectly elastic, but is at the same time composed of molecules, each of which considered by itself is highly elastic. Nor is it a thin slip only which must display such phenomena. All that has been advanced must obviously hold good also in reference to a whole lamina, as, for instance, a thin transverse section of a cylinder such as a wire, connecting the two poles of a galvanic system—the only difference being, that instead of *linear* as in the case illustrated, the form of the central or primary vibrating part P must be *circular*, as in Fig. 2, and that of the secondary or reciprocal vibrating parts NN and of the ulterior ones, where they exist, *annular*. Let us now see whether, by the application of such a principle, the characteristic phenomena of electricity may not be immediately deduced.

PHENOMENA.

Electric currents deduced.—Let AB, Fig. 3, be a cylinder or wire favourable for the developement of the kind of action described and for its propagation through it; and let it be conceived to be of such elementary tenuity, that one series of elementary impulses applied in the direction of the axis, (as, for instance, by the successive incidence of molecules dissolving those of the axis one after another,) may be capable of throwing the whole into a state of forced-undulatory action from the centre to the circumference. Then, upon causing a series of periodical impulses such as those described, to play upon one end of the axis, as, for instance, upon A, the motion, when embodied in the elementary cylinder and propagated from A to B, must obviously, according to the principle we have laid down, be distributed in two currents, as represented in PNN, Fig. 4, parallel to each other but in opposite directions, and equivalent to each other in the quantity of motion which they convey but so related, that the secondary or reciprocal NN embraces the primary P as the circumference of a cylinder embraces its axis, the amplitudes and periods of the oscillations in the central or primary current being larger than those of the peripheral or secondary current.

If now AB, instead of being a cylinder of infinitesimal tenuity as we have just supposed, be viewed as a cylinder of sensible dimensions, as, for instance, a copper-wire; and that, instead of one series of recurring impulses, a number, corresponding to the increased magnitude of the cylinder, is impressed upon A, then is the case assimilated to those which actually occur in experiment, and the following state of things may be deduced 1. As the larger cylinder may be viewed as composed of a fasciculus of elementary cylinders bound together, no reason appears why the currents traced out in reference to the elementary cylinder, should not equally be developed, at least on the surface of the larger one. 2. In the interior, however, it is to be expected that they shall destroy each other *by interference;* and that the vibratory action of that region, instead of existing in a state of currents, shall exist in a state of confusion and tension and of pressure on all hands, in a plane at right angles to the direction of the currents, that is at right angles to the axis, so as ever to tend to throw itself upon the surface.

Hence, according to these views, we are to expect in a cylinder, as for instance a wire, on one end of which a recurring series of elementary impulses are impressed, two superficial currents pursuing opposite directions; but the periods of the vibrations of the molecules in that current which proceeds from the end where the action is, we are to expect to be of greater extent and duration than those of the reciprocal current, which pursues the opposite path. And, in order to impart greater energy, consistency, and symmetry to these currents, it will obviously contribute very much, if, in addition to the series of impulses already applied to one end and directly developing the primary current described, we adopt means for instituting another series of impulses at the other end, calculated to develope vibrations whose periods shall coincide with those of the current proceeding out from that end, that is, with those of the reciprocal current. Now, this, it may be perceived, is such an arrangement as obtains in reference to the wire uniting the extremities of a galvanic system, and in other similar combinations.*

* Here it may save future circumlocution if we give three definitions. First, then, where the vibratory action is not disposed in currents, but in a state of confusion, all the individual undulations opposing and stifling each other, as has been described

The Accumulation of opposite Electricities at opposite ends or poles deduced.—Suppose that, by some internal mechanism, such as that which exists in the tourmaline and similar bodies, the currents described in the preceding paragraph can be permanently kept up; while, at the same time, the cylinder whose undulatory action is thus disposed in currents, is insulated or surrounded by a medium which can take on the action in the cylinder only with extreme difficulty; so that the action in the cylinder cannot proceed far beyond P on the one hand, or N on the other, as, in conformity with the first law of motion, it must ever tend to do. Then must there necessarily result two accumulations of this peculiar mode of action at the ends of the cylinder, viz. of positive at P, and of negative at N. The motion, in virtue of the sustainment of the currents from end to end, ever flowing in equal quantities towards the two extremities and prevented by the insulation from flowing farther, must tend to charge the matter on these ends and in the surrounding medium, with as much as it can accommodate, or until the tension of the accumulations there balances that of the currents themselves. Moreover, these two accumulations must be equivalent to each other in their tension and quantity, but yet not identical in every respect, as may be inferred from what has been already advanced. With regard to their form, or that of the strata around the ends in which the undulatory action possesses equal intensity whether in the ether, air, or invisible extension of the matter of the ends themselves, it appears that it shall ever tend to be as spheroidal as the form of the ends and the course of the current will admit. For such a tendency to sphericity of distribution in motion prevented from flowing continuously on and obliged to turn back, results directly from the first law of motion. As to the law of the decrease of energy also, there can be no doubt but it will be the same as that displayed by other radiant modes of action. In a word, it appears that the results of the geometrical theory of electricity will hold equally true of the view of electric phenomena now advanced, as of the

in reference to the interior of bodies, I shall call it the *chaotic state*. Secondly, since the currents above described are equivalent, mutually dependent, and in opposite directions, it is in the very spirit of physico-mathematical language that we call them *positive* and *negative* in relation to each other, the primary, or that whose amplitudes and periods are the largest, being regarded as the positive.

hypothesis of fluids whose properties have been conjured up to meet the demands of that theory.

Electric Light, and the forms of the positive and negative pencils deduced.—The accumulation of action at P. Fig. 4, which is the primary or positive, in disposing of itself in the medium to which it is supposed to be confined, must obviously spread, in the first instance, from the centre to the circumference, and tend to flow out in what may be called a pencilliform manner, as represented at P. Fig. 5. That accumulated at N., on the other hand, (which, in relation to the former, may, as has already been shewn, be justly called negative,) in disposing of itself in the medium to which it is in like manner supposed to be confined, must flow from the circumference all around towards the centre, and consequently may be expected to sustain great destruction from the collision, pressure, and interference of similar undulations meeting from opposite sides. From N therefore if there be any undulatory action tending to be given off at all, it will not be pencilliform like that of P, but rather radiant or star-like. The negative pole having become the origin of a new or secondary system of vibrations, resulting from the collision and interference of the true negative system, that newly formed system will tend to emanate from N in spherical shells all around. Now, though an elementary cylinder PN, capable of accommodating only one series of recurring impulses and one series of primary undulations, and its reciprocals can neither be found in nature nor produced by art, yet may any point of a body be regarded as such a cylinder with an exceedingly short axis. And therefore, from the foregoing considerations, we are led to infer that the forced vibratory action, whose phenomena we are now tracing, when accumulated at a point, shall display the following features :— 1. The primary or positive action shall tend to be given off in a pencilliform manner, and to proceed in a direction outwards. 2. The reciprocal or negative, on the other hand, will not equally tend to be given off, but rather to indicate the point where the confluence of undulations from different directions takes place, by the developement there of a sphere of secondary undulations.

But how, it may here be asked, shall we obtain satisfactory evidence that such undulation and radiation exist, even

though it were so? In answer to this, it is enough to call to mind what is now the general belief of philosophers, viz. that an universal ether invests all bodies, and is every where present; and that undulations of certain dimensions, instituted in that medium, produce vision, and are denominated *light*. Whenever therefore the undulatory action of N P possesses such elements that they are similar to those which, when they take place in the ether, produce vision, then, on passing off to the ambient medium around the points P and N, *the positive current of undulations, or that emanating from P, will be indicated to the senses by a pencilliform brush of light, while the negative current, or that emanating at N, will be indicated by a sphere or star of light of inferior intensity.* If again, the undulations of NP should be such that they fall beyond the limits of those which alone are capable of giving rise to vision in our eyes, namely, 0.0000266 parts of an inch on the one hand, and 0.0000167 on the other, then the currents may exist, and the undulatory action be given off without any developement of light at all. And hence we see—supposing the theory of electricity adduced to be the true one—that the relative quantities of light discharged from dissimilar bodies can never become a measure of the relative quantities of electricity which escape from them, and that it were quite unsafe to infer, that one body because it gives a spark, necessarily contains a greater quantity of electricity than another which is unable to do so.

How well these deductions coincide with the known phenomena of electricity the author presumes the reader is aware, and trusts the latter will not be altogether indisposed to appreciate the ease with which, according to the view here advanced, the transition is made from electricity to light. On the supposition that electric phenomena are due to the presence and movements of peculiar fluids, the phenomena deduced in this paragraph appear to the author to be incapable of explanation.

The Mutual Effects of opposite polarities deduced.—In order to display with full effect, the phenomena of *discharge* treated of in the preceding paragraph, it must obviously conduce greatly if the pole P, Fig. 4, instead of remaining naked and exposed to the open space around it as has been hitherto supposed, should have the pole N, or a similar one, brought near it, and made to front it. Thus, suppose NP, Fig. 6, to be

composed of flexible materials, and to be bent round, so that P may be made to front N. Then it is plain that the arrangement is most favourable for producing a very full discharge, and a mutual exchange of the forced-vibratory action accumulated in equal quantities at P and N. The central part of the pole N is in such a state of action as to solicit that of the central part of the pole P to strike towards it, and the peripheral action of the pole P is in such a state of action as to solicit that of N to proceed towards it. Or, laying aside figurative language, the bearings of the opposite poles upon each other are such, that they must both conspire to induce the same undulatory action upon the etherial medium lying between them. And, therefore, in these circumstances, a mutual discharge must take place at a greater distance, and more completely than when there is no such *disposing influence* as the contiguity of reciprocal poles. It ought also to be shewn that in this case there must exist an attraction between the two poles; but, for a reason given in the next paragraph, this cannot be attempted here.

The mutual effects of similar polarities deduced.—If, instead of two poles, such as P and N, Fig. 6, whose modes of action are reciprocal or supplementary to each other, two every way similar, are exposed to mutual action, then, instead of *dovetailing* into each other, and each tending to exalt the action of the other, it is obvious that they must meet each other in complete opposition like two ivory balls, and the action of each must obviously tend to reverse that of the other. There must be mutual collision between the two; and, as in other cases of elastic impact, mutual resilience or repulsion must ensue. Nor is it to be inferred that the term impact here used, implies visible contact; for the action we are now considering, ever tending to proceed forwards in obedience to the first law of motion, must speedily extend beyond the concrete surfaces of the poles themselves, and be *induced* both upon the air and the ether lying between them. These poles must therefore repel each other, not only when viewed as naked and in contact, but when viewed as encased in air, and at some distance from each other. But this subject cannot be prosecuted without entering into inquiries as to the structure and properties of the air and the ether, which are quite incompatible with

the brevity of this tract. It may be remarked, however, that the air adapted for the gross undulations which produce sound, can only be expected to take on with extreme difficulty and propagate with extreme slowness, a vibratory action of such extreme subtility, as electricity (according to the view here advanced) is supposed to be. The ether on the other hand, adapted to the minute undulations which give rise to vision, may be expected to take on the analogous undulations here treated of, with extreme ease, and to conduct them with extreme velocity. And that this is really the case may at once be seen, by introducing a point discharging electricity into what is usually called a vacuum. Perhaps, indeed, it is only by the aid of the ether (or matter of the Torricellian vacuum) that dry air is capable of admitting the passage of electric action through it at all. In these circumstances, therefore, we cannot hope to be able to discuss at present, the physical mechanism by which two similar poles repel each other, when a mixed atmosphere of air and ether lies between them; and this remark applies with still more force to the attractive agency which subsists between two dissimilar poles. It may, indeed, be questioned whether electrical repulsions and attractions do not depend on a mechanism in all bodies, similar to that in iron whence magnetic attractions and repulsions take their rise. If so, I believe they are not to be explained without a knowledge of the ultimate forms and modes of action in matter. It ought not, therefore, to be taken as any objection to the view of the nature of electric action here advanced, that we are unable to describe fully the mechanism of electric attractions and repulsions; for no other theory has ever attempted to do so, nor indeed does philosophy pretend to be able to give any mechanical account of such phenomena in any instance.

The Phenomena of closed and broken currents deduced.— If two opposite poles are not only approximated to each other, as in Fig. 6, but made to unite, so that the circuit is closed and the course of the currents made continuous, then the conditions are obviously favourable in the highest degree for the symmetry, completeness, and energy of the currents; or, so to speak, for the successive discharge from lamina to lamina. When such an arrangement obtains, every vibration pursues another and rests in the hollow of its back, so that the quantity

of forced-vibratory action, which may be obtained from any given source, will, under this arrangement, be a maximum. But it is no less obvious that, in these circumstances, all sensible polarity and accumulation in particular regions must vanish, and, indeed, all external evidence of any peculiar action at all. The electricity must become latent. But if the circuit be again opened, (supposing always that by some internal mechanism, such as heat acting in a crystalline structure, the symmetrically flowing action is kept up,) then an accumulation must again, as formerly, ensue at each end where the farther progress of the current is interrupted. Nor is it less plain, that if, instead of being merely opened and brought to the state of NP, Fig. 4, the cylinder be broken across the axis into any number of parts, as in Fig. 7, each part must possess a polarised structure similar to the whole, and display an accumulation at each end, —the order of the developement of the poles being such, that, if left to lie in the positions they occupied previously to fracture, all the primary or positive poles must look towards one aspect, as, for instance, the right hand, and all the reciprocal or negative poles towards the opposite aspect or the left hand; or, in other words, they must all be in positions parallel to each other and to the parent cylinder or prism; and, consequently, all the adjacent poles must be successively positive and negative—all which is known to hold good in the actual phenomena.

The conditions of permanent polarity deduced.—In the preceding pages it has been already stated that the forced vibratory action of bodies, whose phenomena we are now inquiring into, may exist in either of two states—namely, in a state where the vibrations possess unity in direction and a rectilinear course, from which two accumulations, in two opposite regions and those phenomena generally which are known by the name of polarity, must result; or, secondly, in a state which has been already described and named the chaotic. The former of these states, we should expect to find in bodies possessing a permanently symmetrical molecular structure or one which is such, that it is better adapted for entertaining and transmitting the system of forced vibrations constituted in it, in certain directions rather than in any other directions; the latter we should expect to find in such bodies as are destitute of any regular molecular structure, and whose mechanical state also

may be called chaotic. Now, bodies possessing the regular symmetrical structure above described must be crystalline. The electricity of crystals, therefore, we should expect to find often in a state of intrinsic polarity; that of uncrystalline bodies in a chaotic state. But in order to develope those accumulations, in opposite regions which naturally result from what may be called a polarised structure, some change from a condition of natural equilibrium will still be required even in crystals possessing such a structure; for polarity, or a condition of existence where motion is locally accumulated in excess in certain regions, is very contrary to the laws of motion; and had it existed during the evolution of the structure of a crystal, and when it was receiving its form, it must have tended to modify that form so as to obliterate the accumulations, either by the alteration of that molecular structure whence they took their rise, or, by supplying more matter towards the poles, so as to engage all the motion tending to accumulate there, and so to preserve a state of equilibrium. It is only, therefore, by causing departures from the natural state of crystals, as, for instance, by pressure or alteration of temperature, that sensible accumulations of electricity in particular regions can be expected—all which is known to hold good.

The phenomena of induction and transient polarity deduced.—But though the forced vibratory or electric action of an uncrystalline body can only be expected to be naturally in a chaotic state, it is obvious that, by bringing such a mass under the influence of another whose electricity is in a polarised state, or in a state of greater or less tension than its own, the electricity of the chaotic body must be arranged or polarised too. Its vibrations must be disposed conformably to those of the polarised body which acts upon it. Thus, let AB, Fig. 8, be a cylinder destitute of any symmetry of molecular structure that might give unity of action and direction to its forced vibrations, as, for instance, let it be a cylinder of a wrought metal; and let NP, Fig. 9, on the other hand, be a cylinder which does possess a structure calculated to give rise to a state of unity in its electrical action, and to currents from end to end, as, for instance, a crystal of tourmaline; then, in bringing P near to A, the former must obviously exert—through the intervening medium which must be polarised in the first

instance—an arranging influence upon the vibratory action of AB, and thus AB must be speedily brought into a state of induced polarity, and display two accumulations of electricity—the negative at the end next P, and the positive at the opposite end.

Neither does this induction of polarity on AB necessarily require any accession to the quantity of the vibratory action in it, or any loss on the part of NP. If there be an equivalent quantity of action in both,—as there always must be in consequence of the third law of motion, after they have been lying beside each other for some time,—the whole developement of polarity in AB, induced by the approach of NP, may be the effect of *arrangement* solely, and not at all of *accession*. But, in consequence of the unity of direction resulting from arrangement, the intrinsic vibratory action of the whole system will become more vigorous. The individual vibrations will no longer stifle and quench each other and impress a state of great *tension* upon the whole, while yet there is but a small *quantity* of action. On the other hand, they will pursue each other without conflict, and relieve the tension over the whole—except at the ends where accumulations must take place. A state of polarity induced in such a way, however, must obviously be only of a transient nature, and so soon as the inducing body is withdrawn, it is only to be expected of the other body that its action will speedily return to the chaotic state. For though such a state may be regarded as to a certain degree unnatural, yet is it not so contrary to the laws of motion as is the local accumulation which polarity implies. From these phenomena it also plainly appears, as a necessary consequence of the proximity of a body in a polarised state to one in a chaotic state, that the region of the latter body adjacent to the former must be brought into a state of opposite polarity, if it be polarised at all. But if the two bodies—supposing neither of them possessed of any intrinsic polarised structure which may supply every moment a certain quantity of electricity—be placed in contact with each other instead of being kept separated by an interval of polarised air or some other medium in a similar state, then, that which is most highly charged must obviously impart of its excess to the other, till the electric state of both is assimilated by the first law of motion, and the distribution equalised in both by the

third. The result, in fact, in this case must be the same as if both bodies were parts of one and the same, which, in point of fact, they virtually are. Now all these deductions are conformable to the phenomena of electricity.

The different kinds of Electricity deduced.—Considering the great variety of molecular structure and mechanical condition possessed by different bodies, it is only to be expected that they shall display very various and dissimilar habitudes with respect to the forced-vibratory action we are now investigating. And first, if the molecules of all bodies be always in a state of continual motion, as in virtue of their specific heat we cannot doubt but they are, it follows that a forced-vibratory action must exist, though in a chaotic state and not in the form of currents, in every body, even supposing that body insulated in space, unless it be absolutely cold. Now such undulatory action being due to the heat of the body may properly be called its *thermo-electricity.* It must be characterised by vibrations of the most minute periods, and must therefore be least of all capable of giving sparks—but not equally incapable, it might be shewn, of developing and giving unity to those still more minute undulæ whence (according to the views of the author) magnetic phenomena take their rise. Its quantity in different bodies, and the periods of the undulations, must vary with the *specific thermal constitution* of the body. But secondly, just as each body according to its thermal constitution, may be expected to possess a proper thermal undulatory action, whose elements or periods shall be peculiar to itself, so may every body according to its *molecular constitution,* be expected to possess a proper molecular undulatory action, whose elements or periods shall be more congenial to its peculiar constitution than any other; and this, since the specific character of bodies depends on their molecular constitution, may be called the *specific electricity* of bodies. It must be characterised by undulations usually of larger elements or periods, and consequently of greater tension than those of thermal electricity; and from it sparks will therefore be more easily obtained. It will also be perceived, according to the principles of our theory, that these two electricities, the thermal and specific, when co-existing in the same body, must always tend to become the reciprocals of each other, that is, to be positive and negative in relation to each other.

The relationship of different bodies to electrical action deduced.—It has just been stated that from this fact (that every body has a peculiar molecular structure) it may be expected that it shall also have a peculiar system of forced-vibratory action more congenial to the intervals and positions of its molecules than any other. Now, where this is eminently the case, so that the body does not admit of the undulatory systems of other bodies being induced upon it, but only of its own being excited in it, the body will be *an insulator* of all other bodies, or *non-conductor* of all other electricities. Again, where its molecular structure is such, that while it is favourable for the mode of action now inquired into, it propagates that which is excited in any region but slowly forward through the mass, so that a considerable degree of tension may be produced in one region and preserved for a time without diffusion, it will possess the properties of what are denominated *electrics*. Again, if its aptitude for undulatory action be so limited, that it admits only of the institution of one system of vibrations and not at all of the reciprocals of these, it will fulfil the conditions of *an unipolar body*. When, on the other hand, its molecular structure is so unelastic, so dense, and so chaotic, that, besides its proper thermal and specific undulatory action, it admits of vibratory systems possessing other periods, such as are proper to other bodies, to be superinduced upon it, and propagates them forward with ease and in any direction, it then possesses the power of *a conductor*. Still however, though we might expect to find many bodies possessing such a property in a very considerable degree, we can scarcely suppose any body, not even the ether itself, to possess it in so entire a degree, that it could conduct all systems of forced vibrations—*i. e.* all electricities—with equal ease and to equal distances. In every body, undulations of certain magnitudes and intervals must be more congenial to its structure than certain others, and the former must be conducted with greatest facility. But those undulations, whose elements are most congenial to the intimate structure or mechanical state of the body, constitute its specific electricity, as already explained; hence it appears that *every body must conduct best its own specific electricity, and that of others when possessing similar elements*. Hence, also, it appears, that bodies viewed in respect

of their electrical habitudes, admit of being sorted in pairs according to a very interesting relationship, namely, when the elements of the secondary or reciprocal vibratory action in the one either extant or tending to be developed, possess the same elements as the primary action in the other, that is, *bodies must admit of being sorted in pairs whose electrical habitudes are positive and negative in relation to each other.*

Electricity by contact, and the application of heat, deduced.—From the two facts adduced in the preceding paragraph and printed in italics, it follows that a positive and negative body favourable for such an experiment (as, for instance, a disk of zinc and a similar one of copper) must, when brought in contact, each exalt the electric state of the other, and develope a certain quantity of its own electricity above that which existed previously to contact. For since each conducts its own electricity best, the copper, which is supposed to be negative in relation to the zinc, must, on being brought into contact with the zinc, conduct its negative electricity in preference to its positive. Thus, by the contact of the copper disk, the chaotic state in the electric action of the zinc must be reduced. The negative vibratory system of the latter must pass upon the copper, which implies that its positive undulations pursue an opposite course; and thus the electric action of both copper and zinc must be disposed into two currents parallel to the axis of the combination—the positive current ever flowing into the zinc as from the copper, the negative current into the copper from the zinc. Hence, if the two form a cylinder, one-half composed of zinc the other of copper, and they be firmly in contact, the pole of the zinc may be expected to be found permanently positive, that of the copper permanently negative. If again they are not cylinders, but simply disks, then, in order to discover the exaltation of electrical state which each has sustained by contact with the other, it may be expected to be necessary to withdraw them from contact, and then test them with the electrometer; for while they are in contact the electrical tension of both must be diminished, (except at the ends or poles when they are cylinders, and even then no great tension can be expected because they are conductors,) by the state of symmetry in the electrical action induced, and the momentary accumulations on the surface of each must

immediately pass upon the other, in virtue of the conducting power of both. But when they are removed from contact, the electricity of the one cannot pass upon the other, the symmetry of the action also must be destroyed, and the tension consequently increased; and as has been already explained (page 12), the whole of the positive action of the zinc, and the negative action of the copper, must be thrown upon the respective surfaces, and hence each disk may now be expected to affect the electrometer with its own electricity.

By the aid of the same principle it may be easily discovered, that the application of heat to the extremity of one body, such as a bar of bismuth, and still more to the united extremities of two, such as bismuth and antimony whose *thermo-electricities* are positive and negative respectively, must reduce the chaotic state of the electricity of both, and dispose it into currents; in order to bring which to a maximum of action, it will only be necessary to close the circuit, conformably to what has been already advanced on this subject in page 17 of this paper.

Electricity by chemical action deduced.—If one end of a conductor, as, for instance, of a rod or plate of zinc, be immersed in a menstruum, electric polarity must obviously be developed, provided chemical action ensue. For chemical action, similarly to an increase of temperature, must increase the quantity of forced-vibratory action at the region where it is going on. Moreover (unless it were a case of multiple-solution equally impressing the positive and the negative systems of undulation proper to the conductor as its own) it must also give a direction away from the region of action, either to the negative or positive system of undulations developed in the conductor, according as the movements of the solvent molecules are most harmonious with the one or the other; and consequently it must determine the end of the conductor not immersed to be either a negative or a positive pole. But such a state of things implies that the end immersed is the reciprocal pole; and thus by chemical action at one end, the electric action of a conductor must be exalted and polarised. Now from such a state of things the phenomena and the various conditions necessary to the effective and sustained action of a galvanic combination may be deduced. Thus, according to these views, it must contribute greatly to the permanence and energy of chemical action and the

electricity and polarity dependent on it, if the menstruum admits of an analogous mode of undulatory action being induced in it, —the undulations in the system of *solvent* molecules flowing in towards the region of action, and those in the system of *dissolved* molecules flowing out from the region of action. Moreover, if to the conductor already immersed another conductor be attached and placed opposite in the liquid, which is positive or negative in relation to the first and therefore every way favourable for sustaining the mode of action instituted by the first, it must obviously contribute greatly (as the closing of a circuit always must do) to the energy and continuity of the electric action; and must in the present instance be the more valuable, because a state of polarity in such a considerable breadth of a liquid as is here supposed to exist in the apparatus, must be somewhat difficult to sustain, while nevertheless in the combination now treated of, the liquid performs such an important part, that it may be compared to a magnet, the opposite and connected conductors merely to its armatures.

Composition and decomposition by electric action deduced.— Since two bodies or systems of molecules, which according to the views here advanced are positive and negative in relation to each other, are such that the undulatory action of each tends to develope that of the other as its own reaction, the two together must be peculiarly fitted for forming one system or combination in equilibrio. The undulatory systems in both must also necessarily be in opposite directions; therefore, if two systems of molecules, whose specific undulatory systems are thus positive and negative in relation to each other be intermixed, they must tend to interlace each other symmetrically, and the two to form one compound system—that is, they must tend to unite. But if the undulatory action native and proper to them, and in virtue of whose mutual correspondency they tend to unite spontaneously, be destroyed, and a new system of undulatory action induced—as must be the case when a chemical compound is made part of a voltaic circuit whose undulatory elements are incongruous with its own—then, decomposition must be expected, or, at least, a *conatus* in the constituent molecules to arrange themselves more in harmony with the new and uncongenial action forced upon them.

Magneto-electricity deduced.—The natural magnet is a

body tending to be crystalline, in which therefore we are led to infer that the magnetic molecules are in parallel positions; and all the manipulations by which magnetism may be induced upon steel bars are just such movements as would be resorted to, were the object of the operation to give unity of direction to the superficial molecules of the mass to be magnetized; and there are other arguments in favour of this view which cannot be touched on here. When the magnetic structure is suddenly induced therefore, there is reason to believe that the superficial molecules of iron are forced from their original inverse position (or positions of equilibrium) into positions of parallelism with each other. Now, wherever a sudden change takes place in the molecular arrangement of the constituent particles of a body, it follows that a momentary forced-vibratory action must be simultaneously developed; and hence at the moment when the magnetic structure is induced upon a bar of iron, and equally when that structure is destroyed and the molecules suddenly return to their positions of natural repose, a developement of electricity may be expected. Moreover, the unity of direction assumed by the molecules of iron during the assumption of the magnetic arrangement, and the uniformity of the movement wherein their return to their original positions must consist, must also tend to give polarity to the electric action, that is, to dispose as currents the forced vibration developed. Such magneto-electric action however can obviously only be of momentary duration, or such as may without impropriety be called impulsive—all which is agreeable to the phenomena.

But here the subject passes into that of magnetism and electro-magnetism, in order to discuss which would, as has been already hinted, require us to go far deeper into the consideration of the intimate structure of bodies.

In the preceding paper some of the most common phenomena of electric excitement and polarity have been passed over without notice, as, for instance, their developement in solids by friction. My reason is, that the ordinary phenomena of the electric apparatus seem to me to result so obviously from the principle on which in the preceding paper all electric phenomena are made to depend, that I have omitted them to give place to an explanation of others which seemed to require it more.

ON LIGHT.

The preceding views may be regarded as an extension to the phenomena of electricity of the undulatory theory, which when modified according to the structure and inertia of the media that undulate, has been already applied so happily to explain the phenomena of sound on the one hand and of light on the other. I propose to subjoin a few remarks on the application of this theory to LIGHT—an application which appears to me of such importance, that nothing in philosophy seems more desirable at the present moment than to place it in such a point of view as would secure its general reception with men of science. In its present form however there is too good reason to think that its reception will be confined to the few in whom there exists such a taste for the beautiful in analysis and demand for mathematical operations as may serve to reconcile them to very fictitious hypotheses. Will the reasoning even of Sir J. Herschel make many converts? "We do not hesitate," says he, "to attribute to the fluids which are imagined to account for the phenomena of heat, electricity, magnetism, &c. properties altogether repugnant to our ordinary notions of fluids, and why should we deny ourselves the same latitude when light is to be accounted for? It is true the properties we must attribute to the ether appear characteristic of a solid rather than of a fluid, and may be regarded as reviving the antiquated doctrine of a plenum. But if the phenomena can be thereby accounted for, *i. e.* reduced to uniform and general principles, we see no reason why that, or any still wilder doctrine should not be admitted, not indeed to all the privileges of a demonstrated fact, but to those of its representative or *locum tenens* till the real truth shall be discovered. Assuming it then with M. Fresnel as a

postulatum, that the vibrations of the ethereal molecules which constitute light are performed in planes at right angles to the direction of the rays' progress, let us see what account can be given of the phenomena of polarised light."* Now, granting to the author of this paragraph that character which, in the place where it stands, (Discourse, sect. 5,) he so beautifully ascribes to the true philosopher, viz.—"to hope all things not impossible, and to believe all things not unreasonable." How, I would ask, can any one feel any comfort in admitting the co-existence in an eminently elastic medium of such a medley of independent yet conflicting, and discordant yet uniformly recurring motions, as it is necessary to assume before the phenomena of colour and polarization can be accounted for by the undulatory theory in its present form? and why should any one attempt to explain such complicated and varied phenomena as those of physical optics, while at the same time he excludes from his regard that feature in the medium of light which obviously must, more than any other feature, determine the modes of action which shall take place in it, viz. *the form and relative positions of the ethereal molecules?* If it be objected that that form and these positions cannot be discovered, it may be answered that the attempt has not yet been fairly made, that it is certainly worth the trying, and at all events, that if we confess ourselves ignorant of the form of the ethereal molecules, we should also confess ourselves ignorant of the mechanism of the ethereal medium, and quite incompetent to delineate the mode of action which will obtain in it during the propagation of light. If it be farther objected to the particularizing of the form of the ethereal molecules, that as soon as any thing else besides mere motion and laws of action (as for instance a specific form) is assigned to a molecule, an element is then introduced which defies in its present imperfect state the geometrical mode of investigation, and that therefore the consideration of the form of the ethereal molecules ought to be excluded as long as possible—what is this but to treat nature as subordinate to the symbols of algebra, to forget her constancy, and to ascribe to her a structure and economy ever varying with the changes of mathematics?

But may not the transverse vibrations of the modern theory

* Ency. Metrop. Light, Art. 976.

be made use of to guide us to the forms of the ethereal molecules? Are they not indications of the peculiar features of these forms? It will be granted by every one, that they are most serviceable in giving us an idea how the phenomena of physical optics might arise, were the molecules of the medium of light physical points merely, capable of executing spontaneously whatever motions philosophers might be pleased to assign to them. May not these cycles and epicycles of vibrations then be replaced by something more probable, and more like nature, and equally available for explaining the phenomena? That they may, must (I think) be granted. For, will not the effect of a physical point vibrating backwards and forwards in the same line continually with an infinite velocity, be the same as to the production of phenomena as that of a physical line occupying the course of the vibration? And if the excursion of the molecule be very short, then, even though the velocity of vibration be finite, still may not the effect in both cases be sensibly the same? Let us then replace the lines of transverse vibration in Fresnel's Theory by physical lines, and regarding these as eminent features in the structure of the ether, let us observe the result at which we arrive by such a process. And for this purpose, let us assume any approved illustration of the undulatory theory in its present form, as the basis on which to construct the ether according to the principle which has been laid down, as for instance, the following by Professor Airy.* "As a simple instance of our general supposition, suppose 1000 similar vibrations in one plane to be followed by 1000 vibrations of magnitudes equal to the former in the plane at right angles to the former plane; then 1000 in the same plane as the first, &c. The succession of similar waves would be sufficient to give all the phenomena of interference to perfection. At the same time, no colours could be exhibited with a crystal and an analyzing plate. For the first series alone would give rings and colours, but the second would give rings, &c. with intensities exactly complementary to the former; and as these would enter the eye in such rapid succession that we could not distinguish them, we should only observe the combined effect, which would be a uniform white." Now, assuming the vibrations of the simplest

* Professor Airy on the Undulatory Theory of Optics, Tracts, p. 408.

kind, as for instance linear, let *a* Fig. 10 be the line of the first 1000; *b* equal in length to *a*, but at right angles, that of the second 1000; *c* parallel and similar to *a*, that of the third 1000; *d* parallel and similar to *b*, that of the fourth 1000, &c. And to simplify the case as much as posssible without impairing the hypothesis of Professor Airy, let these lines of vibration be conceived as arranged at equal distances behind each other in the direction of the undulation or course of the ray, then here in Fig. 10, we have a representation of the *eminent features* in the structure of a small linear portion on the ether, or what may be called *the osteology* of a ray of the least dimensions. Let us fill it up then, and give continuity to the whole by joining the ends of the lines, and observe what forms we arrive at. This done as in Fig. 11, it is obvious that we develope a series of regular pyramids or tetrahædrons applied to each other by their opposite edges, and constituting what may be regarded as a system of hinges flexible at equal distances in two planes at right angles to each other, or an ethereal filament consisting of laminæ alternately axifrangible in two planes at right angles to each other. We are thus led to indications of a tetrahædral structure in the ethereal medium. What forms of molecules then can give rise to a tetrahædral structure in the aggregate? The tetrahædron itself fulfils this condition most obviously. May not the form of the molecules of light then, or at least of those groups of molecules which never part but act as one individual, be the tetrahædron?

In order to answer this, these two questions demand inquiry. First, is there any verisimilitude in such a hypothesis viewed in relation to the general principles of mechanics and the analogy of nature, but independently of the phenomena of optics? and secondly, does such a hypothesis explain these phenomena?

Now that there is in such a supposition respecting the form of the ethereal molecules the highest degree of verisimilitude must I think be granted; for the tetrahædron is that solid whose mechanical origin is the simplest of all, and that to which we are speedily conducted, whatever hypothesis we make as to the component element of solids, provided only that that hypothesis be of simple character. Thus if with the Pythagoreans and Mathematicians generally we regard a solid as defined by planes, and proceed to construct that solid which

is the simplest and most elementary in this point of view, we are immediately led to the tetrahædron; for it requires only four planes for its construction, while all other forms require a greater number. If again, with Leibnitz, Newton, Boscovich, and most philosophers of the present day, we regard molecules of matter as little bodies possessing attractive forces, it may be easily proved (as is done in *Boscovich's Theoria*, section 239, and may indeed be easily perceived) that, unless some peculiarity of form modify the action of these forces, the first group of molecules or physical points that can be regarded as in any degree perfect, or as possessing the requisites of individuality and stability, is a group of four constituting a tetrahædron. Or, if we still cling to the pure atomic philosophy of the most ancient school, which, jealous lest the attributes of Deity and the province of mind be confounded with that of matter, denies that matter is animated by such forces, and affirms that all physical phenomena might be explained mechanically were we only acquainted with the machinery of atoms, we shall be equally led to the same conclusion;* for this mechanical philosophy forces us to hold that, since the particles of the ether are connected with each other, while at the same time they occupy a very small portion of the space through which they are is extended, they must be connected by elastic filaments, and may be composed of filaments, the whole medium forming a gossamer tissue of most exquisite and infinitesimal tenuity.† Now if we take any number of similar elastic cylinders or filaments, and endeavour to combine them into a stable system, we shall find that after three crossing at their centres at right angles (which forms a very perfect system) no number short of nine can be combined statically except six. But six, when so combined, constitute a tetrahædron; and of such a system the origin may be regarded as extremely simple, since it would immediately result from the coalescence

* See Boyle's Works by Shaw, vol. 1, p. 214.

† It will be perceived that this hypothesis (which at once avoids the difficulties of a vacuum and a plenum, and takes for granted in the least parts of matter a form, which it might be shewn is congenial to the laws of motion,) leads directly to the law of the cycloidal pendulum, as that which must regulate all the vibrations of the ethereal molecules, when their displacement is not great or violent. Query, Is there nothing preposterous in assuming this law as the basis of the undulatory theory, and in assuming at the same time that the ethereal molecules are animated by forces which act as the inverse square of the distance?

and reduction into positions of equilibrium of a pair of the systems of three noticed above.

Thus it appears that under every point of view, and whether we regard the component elements of the molecules of light as planes, points, or lines, we are equally led to the tetrahædron as a most elementary structure. Viewed therefore in relation to the general principles of mechanics, the hypothesis that this is the form of the ethereal molecules possesses great verisimilitude. The same might also be shewn by referring to the analogy of nature. True there still prevails among men of science a prepossession in favour of the Cartesian globules, both in reference to the molecules of the ether and those of all other media. And though it is now obvious to all men that the molecules of bodies do certainly possess *singular points*, where their peculiar modes of action are most intense, yet, so reluctant are most chemists to part with the idea of globularity in the forms of molecules, that they are content to pass off these singular points as indications of poles on spheres; forgetting, it would seem, that poles on spheres are the mere creations of geometry, and neglecting the fact to which nature seems everywhere to point, viz. that if there be any form which, independently of motion, is incapable of permanent and intrinsic polarity, that form is the sphere. The economy of polarised action certainly is this—always to tend to diminish its own intensity. And I think it admits of being shewn, that the process by which this is accomplished consists in obliterating, as far as circumstances will admit, those eminent lines in the symmetry of the polarized body, which would be regarded as axes of its form, and which are the foci of polarised action; that is, the economy of polarised action is to reduce, as nearly as circumstances will admit of, those forms where it operates to spheres. According to such a view, therefore, the progress of chemical combination or neutralisation would always be from the more angular to the mere spheroidal, leading us to infer that the molecules of the most elementary medium in nature should also be the most highly angular, that is, the molecules of the ether, tetrahædrons.

Thus far the way seems clear for inquiring whether the hypothesis that the molecules of the medium of light possess a pyramidal form will explain the phenomena of physical optics in a simple and satisfactory manner, and without superadding to the

Huygenian theory any arbitrary and empirical accessories, such as vibrations of all sorts in transverse planes, and no vibrations in the direction of the undulation. Now, I have endeavoured to shew that this is actually the case—that the most characteristic phenomena of physical optics arise very simply out of the hypothesis that the form of the ethereal molecule is the regular pyramid; and though the little treatise alluded to* is doubtless very imperfect, yet since there is no other on the same subject, it seems to me not altogether unworthy of perusal. Or if, without taking this trouble, any one who is acquainted with the phenomena of optics, and has a taste for mechanics, will provide himself with a number of small tetrahædral models, and disposing them in those linear or prismatic series of cubical groups of eight, each surrounding octahædral cavities which a symmetrical arrangement of them demands (and of which four are represented in Fig. 12), and enquire into the phenomena of their disturbances from small impulses, on the principle of their mutual relationship being such that they ever tend to preserve the most symmetrical positions which existing circumstances will admit of, I am deeply persuaded that he will speedily observe such indications of the more peculiar phenomena of physical optics, that he will not lay aside these models till he has been led to the conviction that the forms of the molecules of light must be somehow similar.

It was my intention to have shewn here how simply and directly the more eminent and peculiar phenomena of optics may be deduced from such a hypothesis; and for this purpose Figs. 13 and 14 have been copied from the little treatise referred to above. But this tract having already extended beyond its anticipated limits, I shall merely explain these figures.

Fig. 13 is intended to represent a small portion of the front of a wave of common light, or (what is the same) the base of a pencil of common light viewed as a prismatic or cylindrical system of molecules. The lines—consisting of two sets equal in number, and those in each set parallel among themselves, but those in the one set transverse or at right angles to those in the other—represent the positions of the poles of the tetrahædra,

* Inquiries into the Medium of Light and the Form of its Molecules, by J. G. Macvicar, A.M., 8vo; Adam and Charles Black, Edinburgh; Longman & Co. London.

which, in this solid, are not opposite angles as in most others, but opposite edges. Now, whenever a ray of common light is incident upon a dense medium, let us conceive its base where its further progress is interrupted by that medium to possess such a structure, and it must be admitted that phenomena identical with those of optics, so far as our ignorance of the structure of reflecting and refracting media permits us to deduce these phenomena, must result. Thus, suppose such a pencil of light to be incident vertically upon a reflecting plane which exerts no peculiar action on that pencil, but which may be regarded merely as a physical plane, it is obvious in that case that the reflected pencil or wave will have the same structure as the incident one, because all the poles of the ethereal molecules, whether parallel or transverse, apply themselves similarly to the reflecting plane, and consequently act and suffer similarly. But suppose the pencil to be incident upon the reflecting plane at an oblique incidence and symmetrically in relation to the reflecting surface, then it is obvious that one half of the poles of the molecules of light most contiguous to that plane and oscillating above it, impinge upon it conformably and parallel to itself or like scraping instruments; and also in such a way that their connection with those molecules, which are on the same side of the reflecting plane but on the other side of the perpendicular at the point of incidence, is not destroyed. The rays constituting this half of the incident pencil therefore are merely bent at the reflecting plane like hinges, and the motion which streams down them has every facility for streaming up again after reflection, and for constituting a reflected pencil. The other half of the poles of the molecules in the base of the incident pencil, on the other hand, impinge upon the reflecting plane at every oscillation unconformably to itself, and not like scraping instruments but like cleaving instruments; and also in such a way that on the other side of the perpendicular at the point of incidence there can be no molecules symmetrically connected with them. The facilities for reflection in reference to this half, therefore, are much less than those of the other. Hence at oblique incidences of a pencil of common light, partial reflection is to be expected; and the structure of the reflected pencil is to be expected to be different from that of the common light incident, and to consist of an excess of rays having the poles of their molecules conformable

and parallel to the reflecting plane, or at right angles to the plane of incidence and reflection. If now we suppose the reflecting plane to possess also the same aptitude for transmitting light as for reflecting it, but free from every power of destroying or modifying it, then it is obvious that the pencil transmitted must possess a structure exactly complementary to that reflected, and such that the two when reunited must reproduce common light; in other words, whatever excess of rays with their poles at right angles to the plane of incidence and reflection, the reflected pencil possesses the same excess with their poles parallel to the plane of incidence and reflection, the transmitted pencil must possess. And it is only what is to be expected, *first*, that certain reflecting media should be found which, at some angle of incidence or other, should reflect those rays only which are already symmetrically disposed for reflection; and, *secondly*, that, with respect to an obliquely transmitted pencil, it may be so singled by repeated reflections, that at last no rays shall be transmitted but those only which are already most symmetrically disposed for transmission, and least of all for reflection,—that is, as has been already stated, rays whose poles are parallel to the plane of incidence and reflection, and at right angles to those of the reflected pencil. Hence, according to the view now advanced, these must be the developement out of a pencil of common light of two rays polarised in rectangular planes, as rudely represented in Fig. 14. With regard to the polarising angle, and the structure which the transmitted pencil must assume while traversing the transmitting medium, these are phenomena which must depend on the peculiar molecular structure of reflecting and refracting media, and obviously cannot be explained until that structure be discovered. It may merely be stated that the law of symmetry generally, and the character of the symmetry which has now been assigned to the medium of light in particular, lead us to expect, that the reflected ray shall possess its most symmetrical structure when the angle of incidence is such that it shall strike off from the ray suffering transmission at right angles—as is well known to be the case at the polarising angle.

In the above instance, the dense medium on which the light is supposed to be incident, has been regarded as exerting no other action on the light than that of reflection

and transmission in a manner conformably to the symmetry of the ethereal medium itself. But if the structure of the surface on which the light is incident, or that of the medium through which it is transmitted be uncomformable to that of the ethereal medium, and be calculated to impress upon the molecules of light another arrangement than that which is natural to them, then, from such a state of things combined with the sustained effort of the medium of light (arising from its own structure) to resume and sustain the symmetry proper to it, there must result many cases in which the rays shall be twisted, so that the successive poles in a ray shall deviate by a certain small quantity from parallelism, and in a certain length of the ray depending on the motion by which it is actuated, shall complete a revolution either dextrorsally or sinistrorsally, according as the disturbance causing the twist determines—a state of things this, from which a little reflection will shew that phenomena, identical with those of circular and elliptic polarisation, must result. But such inquiries as these, and the whole class of phenomena in which crystalline structures are concerned, I have wholly avoided entering on, believing that such researches never can terminate otherwise than in mere hypotheses, until the actual mechanism of crystalline media is known. It is in this direction (so far as I can judge) that science ought to be pressed forward at the present moment, in order to the true advancement of the theory of optics, as well as of chemistry and physics generally; and, with this view, I have appended to the treatise on light formerly referred to, a discussion in which I endeavour to shew that many of the most remarkable phenomena of nature, and discoveries of atomic chemistry, may be explained, or even deduced mechanically, by proceeding on the principle that the molecules of the medium of light possess a tetrahædral form, and that the molecules of more palpable media are little aggregates of these tetrahædral particles, permanently united in greater or less numbers according as the law of symmetry admits, and more or less disposed for chemical union with each other according as, by doing so, the quiescence and symmetry, or, in a word, the *tessularity* of the compound molecule can be made greater than that of its elements. I have followed out the consequences of this hypothesis to such an extent, and such an

accumulation of evidence in its favour has presented itself on all hands, that it has supplanted in my mind every other hypothesis connected with the constitution of bodies; and I am not without hopes, that, before many years shall have elapsed, it will be possible to demonstrate whether it be true or false. If, for instance, the form and structure of a molecule could be discovered, such as that of sulphur, which is at once a somewhat homogeneous and simple body, which also crystallizes in very peculiar forms, and undergoes a remarkable change when heated to a certain degree, and enters into union with other bodies in a certain quantity or multiple of that quantity; and if it were found that the form assumed, as that of the molecule of sulphur, fulfilled all these conditions, even to the exact angles of the crystals: and if the same were done in reference to several other bodies; this would certainly amount to a demonstration of the truth of the hypothesis. But while our ideas continue to be so indefinite as they are at present respecting heat, the forces which cause cohesion and crystallization, electricity, &c. and the means or mechanism by which the molecules of bodies move and act upon each other, there is not much likelihood of our being able to connect together by a demonstrative process two things so very remote as the form and structure of a single molecule on the one hand, and the form and structure of a crystal on the other, which, however small it may be, if it be large enough to be palpable, doubtless consists of countless millions of individual molecules. Nevertheless it does not seem too sanguine to hope that ere many years have elapsed this may be done.

ON THE

MOLECULES OF BODIES.

Dr Dalton, when in the Chair of the Chemical Section of the British Association at Cambridge last year, expressed his opinion that many advantages resulted from representing the molecules of bodies on paper. This opinion he had himself long before, in common with Dr Wollaston and others, illustrated by his example, and since then Dr Prout has given the sanction of his authority to it also by delineating in his Bridgewater Treatise figures as representatives of the molecules of bodies. Moreover, the figures of that work are more minute than those of Dalton and Wollaston, representing not only the molecule itself, but its general form, axes of polarization, and atmosphere of heat. With regard to the form of molecules, the author makes the following remark :—" Strictly speaking, perhaps this observation (that the ultimate molecules of bodies are either spheres or spheroidal, that is to say, more or less *virtually* globular) is applicable to the forms supposed to be assumed by the influences surrounding the molecules, and by which all their operations are directed, rather than to the absolute forms of the molecules themselves, which, though in many instances virtually exerting spheroidal influences, must in different instances have very different forms," (p. 30.) Under the protection of such great authorities, I have ventured to give a diagram (Fig. 15.) which, viewed as an *ideal* representation of the form and structure of a molecule of some very simple substance, seems to me much more serviceable for explaining the phenomena of molecular action, than any that I have been able to find elsewhere; and which has at least this advantage, that what it does explain, it explains mechanically and therefore intelligibly, and does not ask the aid of those undefinable

atmospheres on which many philosophers now lay the whole burden of molecular agency, and whose questionable nature and mysterious powers seem to entitle them to a place in the fictitious science of Pantheism rather than in true Physics. In the figure referred to there is indeed what may be called an atmosphere; and the nucleus and its atmosphere together completely meet Dr Prout's ideas as to the form of molecules, since here we have "the influence surrounding the molecule" by which (as will be shewn) all its operations are directed "of a spheroidal form," while we have the "absolute form of the molecule itself," or the nucleus "of a very different form." But the atmosphere here delineated is not supposed to consist of particles of caloric, nor of the molecules of the two electric fluids, nor of the matter of polarity, nor of a mixture of several or of all of these substances, but simply of an extension of the matter of the molecule or nucleus itself, in the form of annular and rectilinear filaments of exquisite and altogether impalpable tenuity, whose origin may be thus conceived.

It admits of being shewn (though not in so short a space as this tract admits of) *first*, that if the least parts of matter possess a form congenial with the characteristic of motion, (which is ever to proceed forward in a right line,) they must be filamentary, and either rectilinear or annular according as the motion or undulæ embodied in them reciprocate or circulate; *secondly*, that whatever the intimate nature of matter, and though it be perfectly plastic and indifferent as to form, still, when resolved into filaments in which impulses or undulæ reciprocate or circulate, it must display the phenomena of perfect elasticity; *thirdly*, that such individual filaments, in being combined together into systems which may possess properties fitting them for permanent existence, must be combined in certain numbers only and not any other numbers; and that those that admit of being combined must cross each other at the centre symmetrically, so as to furnish a series of molecules, each consisting of a *nucleus* possessing the form of some symmetrical solid of crystallography and a *gossamer atmosphere*, which must possess the following characteristics:—1. Its form or boundary may on a general view be regarded as always spherical—which ought so far to make it acceptable to philosophers, who, because it is easy to attenuate spheres into

physical points, and to introduce physical points into mathematical calculations, have a great demand for spherical forms. 2. Its structure is radiant, the constituent filaments emanating in a pencilliform manner from the angles of the molecule—which ought also to make it acceptable to philosophers, since it follows from such a state of things that all forces distributed around the molcule similarly to these filaments, must vary as the inverse square of the distance from the point of the nucleus whence the filaments emanate when the latter are rectilinear, and in a higher ratio, for which it forms an interesting speculation to find an expression, when they are annular, (as it will presently appear they must always be when they are capable of giving rise to cohesion and chemical union.) 3. Its substance is such that it *fills* but an exceedingly small portion of the space required to contain it—which ought to recommend it to all who are desirous of having an idea how a variety of bodies all of them very incompressible can nevertheless possess very different specific gravities, and how they can admit of having others combined with them without a corresponding increase of volume ensuing, and especially, how a fluid can admit of the diffusion of other molecules through it so readily, and of their co-existence along with it in the same volume so completely, that the one may almost with truth be viewed as a vacuum to the other. 4. Its mode of action is such (as will be presently noticed) that phenomena identical with those of cohesion, crystallization, chemical combination and decomposition, may be deduced; and also that at a certain temperature its constituent filaments shall be forced to part with their annular form, and burst open and suddenly extend themselves, thus causing at that moment a change of structure and consequently of properties, and such an immense increase in the volume of space through which the molecule extends its perfectly elastic and yet almost vacuous atmosphere, that it may be fully adequate to give a distinct and mechanical idea of the marvellous change of properties and expansion of volume, which the molecules of actual bodies experience when they are changed by heat from the solid or liquid to the aeriform state. Such are some of the properties which much characterize such a piece of mechanism as delineated in Fig. I5.

But what are the modes of action which may be mechanically assigned as proper to such a structure? It has been stated that

the whole is to be viewed as exquisitely elastic. The mode of action, therefore, which we should be led first to deduce as the primary and most central, is a regular pulsatory action of the nucleus, the angles making excursions to and from the centre and oscillating on both sides of their positions of quiescence as long as the disturbance from without continues to agitate the molecule. Now this is a mode of action which a host of philosophers (amongst whom are BACON, BOYLE, NEWTON, CAVENDISH, YOUNG, and DAVY,) have already regarded as identical with heat; and it will be found that it agrees with heat in a wonderful manner as to the effects which it must produce, and even with the description of it, when it is said that "to the influence of heat is due that endless variety of forms which are spread over and beautify the surface of the globe." "Withdraw heat, and instantly all life, motion, form, and beauty will cease to exist, and it may be literally said chaos has come again."* For each excursion of an angle from the centre must, in virtue of the inertia of the filamentary atmosphere investing the nucleus, impress an impulse upon all the filaments connected with that angle; and this impulse must be propagated along these filaments in the form of an undula, or like a ring shot along a rod, or a bead shot along a hair. And thus while the nucleus continues to pulsate, the constituent filaments must be covered with systems of undulæ pursuing each other, continually emanating from one angle, and where the filaments are annular entering into another. Now these undulæ or beads must, in virtue of their uniform tendency in common with all moving bodies to persevere in a rectilinear course, act with a centrifugal force upon the annuli on which they are constituted and round which they travel, and therefore must tend to expand them, and thus to increase the dimensions of the molecule. And its volume, under any given amount of such action, that is, (according to the idea advanced as to the nature of this action,) at any given temperature, will depend on the extent to which the pulsatory action of the nucleus (supposed heat) of the molecule thus propagated into the atmosphere, is able to resist the principle of reaction in the matter or its tendency to contract. It is easy to

* Lardner on Heat, p. 3.

conceive, however, that this action (the supposed heat) may be increased to such an extent that the annuli shall be no longer able to resist the centrifugal force, ever tending to thurst them open. When this epoch, therefore, shall have arrived, the atmosphere of the molecule must undergo a change of structure. All the filaments must become rectilinear, and granting that the matter is very extensible as well as contractile (as is always assumed), a great extension of the filaments in length and consequently of the limits of the atmosphere of the molecule, is to be expected; because the undulæ now, instead of circulating and acting only as tangential forces in extending the matter of the filaments, reciprocate and act with their whole energy in doing so. Moreover, it is very reasonable to suppose that the degree of pulsatory action (supposed heat) sufficient to produce this burst from the annular to the rectilinear structure in the atmosphere of our ideal molecule, may be also sufficient to extend the filaments constituting that atmosphere the moment they are burst open, to the utmost to which they admit of being extended. So that all subsequent accessions of this kind of action (supposed heat) shall merely cause an increase of the force in the filaments ever tending to straighten them when they are any how bent, as by compression; or in other words, shall merely cause an increase of *tension* to the molecule, and consequently to an aeriform medium composed of such molecules, but not of *volume*—supposing all pressure removed. We are thus furnished with a mechanism and a mode of action from which, whatever be thought of them, the following phenomena must result:—

1. When the central action (supposed heat) increases, the volume of the molecule must increase according to a law easily deducible and analogous to those laws which philosophers have attempted to discover in order to express the movements of volume, corresponding to movements of temperature.

2. When the volume of the molecule has increased to a certain amount, its atmosphere must suddenly undergo a change of form, accompanied with a marvellous expansion in the space occupied by it. It must also sustain a corresponding loss of tension, which, being restored by the immediate influx into the nucleus of the motion which actuates the surrounding molecules,

the molecule which has just changed its form, will again become capable, not only of bearing its own weight in its expanded state, but of resisting great pressures.

3. The pressures which it will be capable of resisting must be proportional to the compressions which they effect,—the structure of the whole being analogous to that of a single elastic filament, whose resilience is always proportional to the degree of flexure which compression has effected. Nor, so far as I am able to perceive, is there any of the peculiar features in the constitution of gases, nor of the characteristic phenomena resulting from heat, but the structure now advanced gives us a mechanical idea of them, coinciding in its results with the observed phenomena of nature.

4. Thus when there is any number of such molecules, all of them simple in their structure and in the expanded (aeriform) state, but dissimilar to each other, then the spaces required to contain each or equal numbers of each must both, when wholly uncompressed or under equal pressures, be the same for all; or in other words, whether wholly compressed or under any equal pressures whatever, equal volumes of media composed of such molecules must consist of equal numbers of them. For if, in the first place, we suppose *all compression* absent, then the constituent filaments of all simple molecules being supposed equal in length, the circumscribing volumes of space required for each, however few or many filaments it may consist of, must be the same for all. And the volume occupied by a given number of molecules of one sort must be the same, as the volume occupied by the same number of another sort; because, as has been shewn, (although in the aeriform state the apparatus of mutual attraction vanish,) an apparatus of mutual repulsion exists by which each molecule will thrust away those that are around it until they rest on each other by the tips of their constituent filaments, and thus though equal volumes of uncompressed media composed of dissimilar molecules must contain dissimilar quantities of matter, they must still contain the same number of molecules. But, in the second place, the same state of things must prevail when *equal compressions* are applied, provided only that there be always an equilibrium of pulsatory action (supposed heat) in the molecules of the media compared. For an equilibrium of such action will only hold when the laws of motion are satisfied,

that is, when each molecule has communicated of its action to another, until action and reaction throughout them all is equal. Now this state of things may, in accordance with the first principles of dynamics, be stated on a general view to obtain, when the quantity of motion in each molecule *into* its mass is the same for all—that is, when the amount of the pulsatory action of each molecule in a given time *into* the number of its constituent filaments—that is, when the number of undulæ simultaneously existing on the filaments constituting a molecule *into* the number of these filaments—that is, when the energy of the filaments to retain their rectilinear form or resume it under flexure or compression *into* the number of these filaments—that is, when the tension of the molecule arising from its action (supposed heat) *into* its tension arising from its structure, is the same for all; and, consequently, when its power to resist compression in virtue of its action (specific heat) is great in proportion as its power to do so in virtue of its structure is small; and therefore, finally, when equal numbers of molecules occupy equal volumes, whatever the pressures provided only they be equal, and not so overbearing as to cause mechanical lesions in the structure of the media..

5. Again, when two systems of such molecules, urged by equal pressures, are transmitted in opposite directions through the same or similar pores—as, for instance, those of a stucco plug, —then the relative volumes, which will simultaneously overcome the obstacles to transmission, and escape on the sides opposite to those on which they enter, must be inversely proportional to the square root of the densities of the molecules or media so transmitted. For the process of obstruction must, according to the view here advanced, be one purely of collision; and from this, it must result that the quantity of motion in the two currents which have conflicted and eventually escape, must be equal. But the energy of each (molecule or medium) to overcome obstacles and penetrate, is proportional, not to the simple velocity but to its square *into* its density or mass. Therefore the equation between the two currents, which expresses the result of the conflict, and the penetrating power surviving it, (and which, on one side, consists of one density *into* the square of its velocity, and on the other, of the other density into the square of its velocity,) being resolved into an analogy, gives the velocity of

the one molecule or system of molecules, transmitted in one direction, in the same proportion to the velocity of the other transmitted in the other direction, as the square root of the density of the latter to the square root of the density of the former.

But a little consideration will shew that the same mechanism and mode of action are adequate to give us a similar idea of the other molecular forces, viz. those by which the phenomena of cohesion, crystallization, chemical combination, and magnetism, are produced. For, suppose any angles—as, for instance, the polar angles—those which are highest and lowest in the diagram to be pulsating as has been described, ; and as they are similar in structure and relation, suppose them to be pulsating similarly, and consequently generating on the filaments proceeding out from them, similar systems of undulæ. Then these systems of undulæ or currents emanating from the poles, must constitute such a mechanism that they may not inaptly be compared to pieces of rack work continually thrust outwards from the polar angles. If then, in addition to Fig. 15, we had another similar molecule, and were to bring the pole of the one near the pole of the other, so that the "influence surrounding the one molecule" may bear on that surrounding the other, it is obvious that they must thrust each other away, or repel each other, and that, too, with the greater energy the nearer they are to each other. Moreover, it is obvious that this energy of mutual action between molecules must be greatest when, as in this case, the molecules and angles opposed to each other are similar, and when consequently the system of undulæ or pieces of rack work emanating from the one, exactly fit those emanating from the other. But it will be immediately perceived that this repulsive apparatus at the polar angles is converted into an attractive apparatus at the equatorial angles. For, by tracing the course of any filament, or of the arrows in the diagram, it will be perceived that the system of undulæ which emanates from the polar angles flows into the equatorial angles; and that the same mode of action is as necessarily attractive at the equator as it is repulsive at the poles. A repulsive agency in a molecule therefore (provided its atmosphere be in the annular or unexpanded state) implies also an attractive agency of the same periods or elements in another region; and thus molecules, while they have the

means of repelling each other in one direction, have the means of uniting in another, and with more or less energy, according as the systems of undulæ which belong to them are more or less harmonious,—whence it might be shewn that all the phenomena of chemical affinity may be deduced. But, as has been shewn in reference to the polar angles, the equatorial angles of molecules (though not generally to the same extent) must pulsate also, and consequently currents must emanate and a repulsive apparatus exist there also. And, as has been shewn in reference to the equatorial angles when treating of the currents from the poles, these repulsive currents emanating from the equatorial angles must enter into and be converted into attractive currents at the polar angles. And thus each angle of a molecule, whether polar or equatorial, must have an apparatus at once repulsive and attractive connected with it; and another molecule presented to it will be attracted or repelled at any angle, according as the elements of its own systems of undulæ are most harmonious with the repulsive or the attractive system in that to which it is presented. In this way, an idea may be formed of a mechanical agency, which, so far as I am able to perceive, satisfies all the phenomena of molecular action, and indeed enables us to deduce the known phenomena of crystallization and affinity. Thus when *similar* molecules are aggregating, it follows from the principles advanced, that if they are in circumstances to do so freely (as they may when aggregating from solution) they must unite and cohese by their most quiescent angles. But the most quiescent angles in similar molecules must be homologous angles—whence it might be shewn that crystallization must result. Again, when *dissimilar* molecules are brought within the sphere of each other's action, it might be shewn that they will not observe any such law, but that they will, on the other hand, tend to unite by their most dissimilar, instead of their most homologous angles. Thus we have two modes of union, which, though arising from the same mechanism, obey very different laws, according as the molecules mutually uniting are similar or unlike each other; and in a treatise on the subject it might be shewn, that these two modes explain to every degree of minuteness the relative phenomena of aggregation and affinity.

The distribution of polarity also to which our ideas of molecular

structure lead, in which similar polarities are given at both extremities of the axis, and polarities dissimilar to these at the equatorial region, is, I believe, the only mode of distribution which will be found to accord with experiment and observation; and I cannot but regard it as a great error, into which some who are not much given to err have of late fallen, when they have distributed polarities in their hypothetic molecules in such a way as to indicate opposite polarities at opposite extremities of the axis. The phenomena of the magnetic needle and the popular view of the earth's magnetism, are indeed calculated to betray one into such a view. But let the subject be inquired into, and attempts be made to impart a *self-conservative polarity* to any regular solids, as for instance to variously formed solids of iron, and it will be found that the distribution has not attained to a state of equilibrium till the same polarity is attached to both extremities of the axis, and the consecutive polarity to the equator. The magnetic needle is not a representation of a solid but of the terminal edge of a solid; and with respect to the earth, it is well known that though its magnetic poles are popularly spoken of as on opposite regions of the surface, yet that, in order to explain the phenomena of terrestrial magnetism, it is necessary to suppose them very near to each other and to the centre of the earth. Besides, were it the opposite aspects of molecules that were endowed with opposite polarities, how could both extremities of the axis of crystals be terminated similarly? And still more in crystals possessing double refraction, how could the same system of rings be obtained by looking through the axis in both directions? Much might be said on this subject. In fact, were the distribution of polarity in molecules similar to that which Dr Prout has represented, there is every reason to suppose that every body as well as iron would admit of displaying magnetic polarity, and that every crystal would be a natural magnet. For, in order to explain the phenomena of magnetism according to the views of this tract, it is only necessary to assume that the molecules of iron possess such a form that the angles which terminate their axes possess dissimilar forms, and that a system of such molecules are placed in parallel positions. This structure and arrangement obtained, two currents must flow over such a system parallel but in opposite directions, rendering each end

or pole of that system both attractive and repulsive, but in an inverse or consecutive manner as in the actual magnet.

In order to explain the phenomena of electro-magnetism in like manner, it is only necessary, *first*, to assume that the system of undulæ which may be induced upon the filamentary tissue of the molecules of copper wires, &c. by throwing it into a state of galvanic excitement, are so similar to those of iron that both shall act on each other and attract and repel each other; and *secondly*, to observe that, if the view of electrical phenomena given in the first part of this tract be just, the systems of undulæ on which the phenomena of magnetism depend must always, according to the view now advanced, pursue a course at right angles to those on which the electrical phenomena depend—which is the fundamental relation of electro-magnetic phenomena. Electricity, according to our views, consisting in a *transverse* undulation of a filamentary system, and magnetism and the analogous phenomena consisting in a *longitudinal* procession of undulæ along the same filamentary system, these two modes of action, when exhibited in the same mechanism, must always pursue rectangular courses. Say then that a galvanic current is flowing *along* a copper wire, this implies that a certain portion of the filamentary tissue by which the molecules of copper are interwoven with each other, and which extends (though invisible) to some distance around the wire on all sides, is arranged so that the filaments lie *around* the wire. Hence the magnetic action of the wire must take place transversely to the axis, the magnetic currents flowing round the wire continually, so long as the galvanic current is kept up. As to the particular direction, however, in which each current shall flow, this is just one of those perpetually recurring phenomena which cannot be otherwise than hypothetically explained, until the discovery of the actual structure of the medium in which the phenomena are displayed. It were easy indeed to suggest a state of things which would give rise to phenomena identical with those of the common apparatus; but why not rather attempt to discover the actual form and structure of the molecules of copper, and supersede hypotheses by the perception of things as they are?